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DESCRIPTION

VOLTAGE CONTROLLED OSCILLATOR WITH MODULATION FUNCTION

Technical Field

The present invention relates to a voltage controlled oscillator having a frequency modulation function for use in communication equipment and the like.

Background Art

Figure 25 is a circuit diagram showing an exemplary configuration of a conventional voltage controlled oscillator (hereinafter, abbreviated as a "VCO") having a frequency modulation function used in communication equipment.

In Figure 25, reference numeral 5 denotes an output circuit, 11, 12, 13, and 14 denote varactor diodes, 16 and 17 denote inductors, and 26 denotes a voltage source.

An anode side of the varactor diode 13 and an anode side of the varactor diode 14 are connected to a voltage input terminal, and an anode side of the varactor diode 11 and an anode side of the varactor diode 12 are connected to a modulation signal terminal. A cathode side of the varactor diode 11 and a cathode side of the varactor diode 13 are connected to one end of the inductor 16, and a cathode side of the varactor diode 12 and a cathode side of the varactor diode 14 are connected to one end of the inductor 17. The other ends of the inductor 16 and the inductor 17 are connected to the voltage source 26. The resonance of the inductors and the varactor diodes realizes the VCO.

Frequency modulation is performed by changing a capacitance value of the varactor diodes 11 and 12 by inputting a voltage to the modulation signal terminal.

In the conventional VCO, when the inductors or the varactor diodes vary in inductance or capacitance, the input voltage versus oscillation frequency characteristics (hereinafter, abbreviated as "Kv") of the VCO are changed. When a modulation voltage is input from the modulation signal terminal at a constant amplitude in this state, a modulation factor of an

output signal is changed in accordance with the variations of Kv. In order to obtain a constant modulation factor, it is necessary to configure the VCO such that the inductors are provided as external components so as to allow the inductance to be adjusted, or that discrete components having little variation are used as the varactor diodes. Further, the voltage versus capacitance characteristics of the varactor diodes are not constant, and their nonlinearity also causes a modulation factor to be changed. Consequently, it is difficult to use the VCO over a wide oscillation frequency range.

In recent years, the downsizing of communication equipment has been required, and accordingly there is a need to incorporate a VCO into an IC. In the case of incorporating inductors and varactor diodes in the IC, element variations are larger than in the case where discrete components are used. Accordingly, the VCO is required to have means for compensating a required oscillation frequency range or variations of a modulation factor at the time of frequency modulation.

In conventional VCO circuits, there is no relationship between a voltage for determining an oscillation frequency of the VCOs in a voltage input terminal and a control signal amplitude for determining a modulation factor in a modulation signal terminal, which makes it difficult to compensate variations of a modulation factor. In conventional VCOs with a frequency modulation function, there is no relationship between a voltage input terminal for determining an oscillation frequency of the VCOs and a modulation signal terminal for performing frequency modulation, and they are controlled individually as respective circuits.

Disclosure of Invention

A VCO of the present invention uses a circuit configuration that allows a modulation factor of the VCO with respect to a modulation control current terminal to be expressed as a function of an oscillation frequency of the VCO with respect to a voltage control terminal for an oscillation frequency (Kv). Therefore, it is possible to compensate fluctuations of the modulation factor due to relative variations of elements.

Compensation is performed in the following manner. When a frequency is fluctuated, Kv also is fluctuated at a given rate. On this account, compensation is performed at a reverse rate relative thereto so as to make a modulation factor constant. As a result, the modulation factor is made constant at any oscillation frequency.

Further, in a VCO having a plurality of oscillation frequency bands, which is realized by making a fixed capacitance with respect to a resonant circuit variable so that an oscillation frequency is shifted, Kv is changed at a given rate when a band is switched. Also in the case where a band is switched, compensation is performed at a reverse rate relative thereto, which allows a modulation factor to be made constant even when the band is changed.

In the case where a wide oscillation frequency range is required, compensation with respect to a frequency and compensation between bands are performed in combination, so that a modulation factor can be compensated to be constant.

As a system of a compensation circuit, it is also possible that a compensation rate with respect to modulation data is calculated using frequency data and band data, and the data thus obtained is input to a digital-analog converter, where the data is controlled to be analog data.

In the case of using the digital-analog converter, a filter for eliminating a clock noise of the digital-analog converter may be provided.

Further, in the case of a complicated transmitting system in which a modulation factor signal as a transmission signal has its band limited, a modulation logic becomes very complicated. In such a case, band-limited modulation data is stored in a ROM in advance, and modulation data is compensated based on frequency data and band data and the ROM is controlled, whereby a modulation factor can be compensated to be kept constant.

In a compensation circuit configured actually, compensation with respect to a frequency and compensation between bands can be performed, but a center of a modulation factor is fluctuated due to absolute variations of the circuit. This can be solved by adjusting an output level of the digital-analog converter to be the center of the modulation factor.

As described above, the VCO according to the present invention has a configuration in which a modulation factor can be expressed as a function of Kv. Therefore, even when the VCO with a wide range of element variations is incorporated into an IC, the modulation factor can be compensated easily.

Brief Description of Drawings

Figure 1 is a circuit diagram showing an exemplary configuration of a voltage controlled oscillator with a modulation function according to a first

embodiment of the present invention.

Figure 2 is a circuit diagram showing an exemplary configuration of a voltage controlled oscillator with a modulation function according to a second embodiment of the present invention.

Figure 3 is a circuit diagram showing an exemplary configuration of a voltage controlled oscillator with a modulation function according to a third embodiment of the present invention.

Figure 4 is a circuit diagram showing an exemplary configuration of a voltage controlled oscillator with a modulation function according to a fourth embodiment of the present invention.

Figure 5 is a circuit diagram showing an exemplary configuration of a voltage controlled oscillator with a modulation function according to a fifth embodiment of the present invention.

Figure 6 is a circuit diagram showing an exemplary configuration of a voltage controlled oscillator with a modulation function according to a sixth embodiment of the present invention.

Figure 7 is a circuit diagram showing an exemplary configuration of a voltage controlled oscillator with a modulation function according to a seventh embodiment of the present invention.

Figure 8 is a circuit diagram showing an exemplary configuration of a voltage controlled oscillator with a modulation function according to an eighth embodiment of the present invention.

Figure 9 is a circuit diagram showing an exemplary configuration of a voltage controlled oscillator with a modulation function according to a ninth embodiment of the present invention.

Figure 10 is a circuit diagram showing an exemplary configuration of a voltage controlled oscillator with a modulation function according to a tenth embodiment of the present invention.

Figure 11 is a circuit diagram showing an exemplary configuration of a voltage controlled oscillator with a modulation function according to an eleventh embodiment of the present invention.

Figure 12 is a circuit diagram showing an exemplary configuration of a voltage controlled oscillator with a modulation function according to a twelfth embodiment of the present invention.

Figure 13 is a circuit diagram showing an exemplary configuration of a voltage controlled oscillator with a modulation function according to a thirteenth embodiment of the present invention.

Figure 14 is a circuit diagram showing an exemplary configuration of a voltage controlled oscillator with a modulation function according to a fourteenth embodiment of the present invention.

Figure 15 is a circuit diagram showing an exemplary configuration of a voltage controlled oscillator with a modulation function according to a fifteenth embodiment of the present invention.

Figure 16 is a circuit diagram showing an exemplary configuration of a voltage controlled oscillator with a modulation function according to a sixteenth embodiment of the present invention.

Figure 17 is a circuit diagram showing an exemplary configuration of a voltage controlled oscillator with a modulation function according to a seventeenth embodiment of the present invention.

Figure 18 is a circuit diagram showing an exemplary configuration of a voltage controlled oscillator with a modulation function according to an eighteenth embodiment of the present invention.

Figure 19 is a circuit block diagram showing an example in which a PLL circuit is configured using the voltage controlled oscillator with a modulation function according to the fifth embodiment of the present invention.

Figure 20 is a circuit diagram showing an exemplary configuration of an output circuit shown in Figures 1 to 19.

Figure 21 is a circuit diagram showing an exemplary configuration of a phase comparator and a loop filter shown in Figure 19.

Figure 22 is a circuit diagram showing an exemplary configuration of a current control circuit in the case where compensation is performed based on frequency data.

Figure 23 is a circuit diagram showing an exemplary configuration of a current control circuit in the case where compensation is performed based on band data.

Figure 24 is a circuit diagram showing an exemplary configuration of a current control circuit in the case where compensation is performed based on frequency data and band data.

Figure 25 is a circuit diagram showing an exemplary configuration of a conventional VCO having a modulation function.

Figure 26 is a graph showing an example of the frequency band characteristics of the VCO in the case where a frequency band switching function is used.

Figure 27 is a graph showing the oscillation frequency characteristics of the VCO.

Figure 28 is a graph showing the capacitance change characteristics of a varactor diode.

Best Mode for Carrying Out the Invention

Hereinafter, a VCO with a modulation function according to each preferred embodiment of the present invention will be described in detail with reference to the drawings. In all the drawings, the components having the same configuration and function are denoted with the same reference numerals, and a repeated description thereof is omitted.

Figure 1 is a circuit diagram showing an exemplary configuration of a VCO with a modulation function according to a first embodiment of the present invention. In Figure 1, reference numeral 5 denotes an output circuit, 7, 8, and 15 denote resistors, 9 and 10 denote capacitors, 11, 12, 13, and 14 denote varactor diodes, 16 and 17 denote inductors, 26 denotes a voltage source, 31 and 32 denote transistors, and 33 denotes a current source.

The varactor diode includes any element that has its capacitance changed by a voltage between terminals at both ends thereof.

The inductors 16 and 17, the varactor diodes 11, 12, 13, and 14, and the capacitors 9 and 10 configure a resonant part, which is connected to oscillation transistors 31 and 32 to carry out an oscillation operation.

When no modulation is performed, no current or a fixed DC current flows through a modulation current terminal. A voltage of a voltage input terminal is determined so that the VCO has an oscillation frequency required in this state. Actually, the oscillation frequency of the VCO generally is controlled by a PLL, and a frequency control voltage of the PLL is applied to the voltage input terminal.

Frequency modulation can be performed by changing the non-modulation state into a state in which a modulation current is fed to the modulation current terminal, and changing the capacitance of the varactor diodes 11 and 12 accordingly.

When the oscillation frequency/voltage of the voltage input terminal of the VCO is represented by Kv (the unit: Hz/V), Kv is changed in accordance with relative variations of the elements such as inductors, capacitors, and varactor diodes. Further, due to the nonlinearity of the varactor diodes, Kv is changed even when the oscillation frequency of the VCO is changed.

However, a modulation factor of the VCO of the present embodiment can be expressed as a function of Kv.

For example, when the varactor diodes 13 and 14 are configured by five elements arranged in parallel, and the varactor diodes 11 and 12 are configured by one element, the elements used herein being the same so that variations of the varactor diodes 11, 12, 13, and 14 are suppressed, the relationship between Kv and the modulation factor is represented by the following expression:

Modulation factor = Kv × (1/6) × (modulation current) × (resistance value of resistor 15).

In other words, in order to keep the modulation factor constant, a modulation current as an inverse function of a change of Kv is provided, so that a constant modulation factor can be obtained without an influence of relative variations of the respective elements.

The output circuit 5 takes a signal from the resonant part. An example of the output circuit 5 is shown in Figure 20.

Figure 2 is a circuit diagram showing an exemplary configuration of a VCO with a modulation function according to a second embodiment of the present invention. The VCO of this embodiment is different from the VCO shown in Figure 1 in that a frequency band switching function is added.

In Figure 2, reference numerals 18 to 21 denote capacitors, and 22 to 25 denote switches. These elements have a function of connecting or disconnecting a fixed capacitance to or from the resonant part or changing a capacitance, and allow an oscillation frequency of the VCO to be shifted, independently from a voltage of the voltage input terminal. Consequently, it is possible to configure the VCO that has a plurality of frequency bands with respect to a change of a voltage of the voltage input terminal. As a result, by switching a frequency band, a wide oscillation frequency range of the VCO can be realized. Even when the frequency band is switched, a modulation factor satisfies the relation expression described in the first embodiment.

Figure 26 shows the VCO characteristics in the case where the frequency band switching function is used. In Figure 26, capacitances C18 and C19 (C20 and C21) of the capacitors 18 and 19 (capacitors 20 and 21), respectively, are set so as to satisfy the following expression: C18 (= C20) < C19 (= C21). The characteristics shown in Figure 26 are obtained in the state where frequency modulation is not performed, that is, no current or a constant current is input to and output from the modulation current terminal.

From this state, a current in accordance with a frequency modulation factor is input to and output from the modulation current terminal, so that frequency modulation can be performed mainly with respect to the VCO oscillation frequencies in Figure 26.

Figure 3 is a circuit diagram showing an exemplary configuration of a VCO with a modulation function according to a third embodiment of the present invention. The VCO of this embodiment is different from the VCO shown in Figure 1 in that a current control circuit 6 for compensating a modulation factor is added. In Figure 3, the current control circuit 6 is controlled so that a predetermined modulation factor is obtained from frequency data and modulation data.

Herein, the frequency data indicates a value of a voltage applied between terminals of the varactor diode in a given frequency band. The VCO has the oscillation frequency characteristics precisely as shown in Figure 27 due to a capacitance change of the varactor diode. This is because the capacitance change of the varactor diode has characteristics as shown in Figure 28 with respect to the voltage applied between the terminals of the varactor diode. A value obtained by differentiating the oscillation frequency characteristics of the VCO corresponds to Kv. Thus, unless the inclination of the VCO frequency characteristics is constant, a constant modulation current input from the modulation signal terminal alone allows the modulation factor to be deviated in an amount corresponding to a deviation of the inclination. On this account, by adjusting a modulation current so that the characteristics of the capacitance change of the varactor diode are compensated, a modulation factor that is constant at any VCO oscillation frequency can be obtained. A compensation value may be obtained either by performing an inverse operation from a set frequency in accordance with the characteristics of the VCO or by using a voltage of the voltage input terminal in the state of a lock operation in the PLL.

The modulation data indicates a modulation signal before being compensated and in the case of FSK (Frequency Shift Keying), a signal having a constant modulation amplitude in accordance with a modulation factor. The current control circuit 6 modulates the modulation data with a conversion circuit such as a gm (mutual conductance) conversion circuit in accordance with the frequency data, thereby obtaining a predetermined modulation current.

Figure 22 is a circuit diagram showing an exemplary configuration of

the current control circuit 6 in the case where compensation is performed based on the frequency data. In Figure 22, this is a gm conversion circuit, which allows a conversion of an amplitude in accordance with the modulation data into a current to be fed to the modulation current terminal. When a current source 39 has a current value I1, and current sources 43 and 44 have a current value I2, a gm value is determined by the ratio between I1 and I2. This circuit is configured such that when a current flowing from a corrector of a transistor 60 has a value I3, the values I2 and I3 satisfy the following expression: $I2 = A \times I3$ (wherein A is a constant) or $I2 = A \times I3 + B$ (wherein A and B are constants). I3 is a value of a current that is changed in accordance with the frequency data (voltage applied to the varactor diode), and a modulation factor is changed when Kv is changed due to the diode characteristics shown in Figure 28. This circuit allows the modulation factor to be compensated by changing the value I3 in accordance with a capacitance change ratio of the diode characteristics.

Figure 4 is a circuit diagram showing an exemplary configuration of a VCO with a modulation function according to a fourth embodiment of the present invention. The VCO of this embodiment is different from the VCO shown in Figure 2 in that the current control circuit 6 for compensating a modulation factor is added. In Figure 4, the current control circuit 6 controls a modulation current from frequency band data and the modulation data so that a predetermined modulation factor is obtained.

This control is required in the following reason. That is, when a frequency band is changed, the inclination of the oscillation frequency of the VCO is changed as shown in Figure 26, and thus a modulation factor has to be compensated in accordance with the band. By performing such compensation, a deviation of the modulation factor due to a change of Kv caused by changing the frequency band can be eliminated.

Figure 23 is a circuit diagram showing an exemplary configuration of the current control circuit 6 in the case where compensation is performed based on the band data.

A gm value is changed by changing the current value I2 in accordance with the band data, and a deviation of the modulation factor occurring when a band is changed can be compensated. This circuit is operated such that switches 79 to 82 are opened or closed in accordance with the frequency band, thereby changing the gm value.

Figure 5 is a circuit diagram showing an exemplary configuration of a

VCO with a modulation function according to a fifth embodiment of the present invention. The VCO of this embodiment is different from the VCO shown in Figure 2 in that the current control circuit 6 for compensating a modulation factor is added. In Figure 5, the current control circuit 6 controls a modulation current so that a predetermined modulation factor is obtained from the frequency data, the frequency band data, and the modulation data.

Figure 24 is a circuit diagram showing an exemplary configuration of the current control circuit 6 in the case where compensation is performed based on the frequency data and the band data. An operation of this circuit is a combination of the operations of the circuits shown in Figures 3 and 4.

Figure 6 is a circuit diagram showing an exemplary configuration of a VCO with a modulation function according to a sixth embodiment of the present invention. The VCO of this embodiment is different from the VCO shown in Figure 1 in that a digital-analog converter 27 from which a current for compensating a modulation factor can be output and an arithmetic circuit 28 for controlling the digital-analog converter 27 are added. The frequency data and the modulation data are input to the arithmetic circuit 28, and a compensated modulation current is controlled by the digital-analog converter 27 so that a predetermined modulation factor is output from the VCO.

Figure 7 is a circuit diagram showing an exemplary configuration of a VCO with a modulation function according to a seventh embodiment of the present invention. The VCO of this embodiment is different from the VCO shown in Figure 6 in that a filter 29 from which a current for compensating a modulation factor can be output is provided between the digital-analog converter 27 and the modulation current terminal. In Figure 7, the filter 29 has a function of eliminating a clock noise of the digital-analog converter 27.

Figure 8 is a circuit diagram showing an exemplary configuration of a VCO with a modulation function according to an eighth embodiment of the present invention. The VCO of this embodiment is different from the VCO shown in Figure 2 in that the digital-analog converter 27 from which a current for compensating a modulation factor can be output and the arithmetic circuit 28 for controlling the digital-analog converter 27 are added. The frequency band data and the modulation data are input to the arithmetic circuit 28, and a compensated modulation current is controlled by the digital-analog converter 27 so that a predetermined modulation factor is output from the VCO.

Figure 9 is a circuit diagram showing an exemplary configuration of a VCO with a modulation function according to a ninth embodiment of the present invention. The VCO of this embodiment is different from the VCO shown in Figure 8 in that the filter 29 from which a current for compensating a modulation factor can be output is provided between the digital-analog converter 27 and the modulation current terminal. In Figure 9, the filter 29 has a function of eliminating a clock noise of the digital-analog converter 27.

Figure 10 is a circuit diagram showing an exemplary configuration of a VCO with a modulation function according to a tenth embodiment of the present invention. The VCO of this embodiment is different from the VCO shown in Figure 2 in that the digital-analog converter 27 from which a current for compensating a modulation factor can be output and the arithmetic circuit 28 for controlling the digital-analog converter 27 are added. The frequency data, the band data, and the modulation data are input to the arithmetic circuit 28, and a compensated modulation current is controlled by the digital-analog converter 27 so that a predetermined modulation factor is output from the VCO.

Figure 11 is a circuit diagram showing an exemplary configuration of a VCO with a modulation function according to an eleventh embodiment of the present invention. The VCO of this embodiment is different from the VCO shown in Figure 10 in that the filter 29 from which a current for compensating a modulation factor can be output is provided between the digital-analog converter 27 and the modulation current terminal. In Figure 11, the filter 29 has a function of eliminating a clock noise of the digital-analog converter 27.

Figure 12 is a circuit diagram showing an exemplary configuration of a VCO with a modulation function according to a twelfth embodiment of the present invention. The VCO of this embodiment is different from the VCO shown in Figure 7 in that a ROM 30 in which a data signal corresponding to an address signal from the arithmetic circuit 28 is stored is provided between the digital-analog converter 27 and the arithmetic circuit 28. The provision of the ROM 30 allows the circuit configuration of the arithmetic circuit 28 to be simplified and a more complicated modulation signal to be output by inputting band-limited modulation data or the like to the ROM 30 in advance.

Figure 13 is a circuit diagram showing an exemplary configuration of a VCO with a modulation function according to a thirteenth embodiment of

the present invention. The VCO of this embodiment is different from the VCO shown in Figure 9 in that the ROM 30 in which a data signal corresponding to an address signal from the arithmetic circuit 28 is stored is provided between the digital-analog converter 27 and the arithmetic circuit 28.

Figure 14 is a circuit diagram showing an exemplary configuration of a VCO with a modulation function according to a fourteenth embodiment of the present invention. The VCO of this embodiment is different from the VCO shown in Figure 11 in that the ROM 30 in which a data signal corresponding to an address signal from the arithmetic circuit 28 is stored is provided between the digital-analog converter 27 and the arithmetic circuit 28.

Figure 15 is a circuit diagram showing an exemplary configuration of a VCO with a modulation function according to a fifteenth embodiment of the present invention. The VCO of this embodiment is different from the VCO shown in Figure 12 in that the digital-analog converter 27 is provided with a function of compensating an output level thereof based on amplitude compensation data. This function is provided to compensate amplitude variations when a signal passes through the ROM 30, the digital-analog converter 27, and the filter 29, so as to obtain a modulation factor of the VCO that is adjusted to a center of the standard level.

Figure 16 is a circuit diagram showing an exemplary configuration of a VCO with a modulation function according to a sixteenth embodiment of the present invention. The VCO of this embodiment is different from the VCO shown in Figure 13 in that the digital-analog converter 27 is provided with the function of compensating an output level thereof based on the amplitude compensation data.

Figure 17 is a circuit diagram showing an exemplary configuration of a VCO with a modulation function according to a seventeenth embodiment of the present invention. The VCO of this embodiment is different from the VCO shown in Figure 14 in that the digital-analog converter 27 is provided with the function of compensating an output level thereof based on the amplitude compensation data.

Figure 18 is a circuit diagram showing an exemplary configuration of a VCO with a modulation function according to an eighteenth embodiment of the present invention. The VCO of this embodiment is different from the VCO shown in Figure 1 in that the polarity of the varactor diodes is reversed.

In Figure 18, with the polarity reversal of the diodes, a cathode side of each of the polarity-reversed varactor diodes 13 and 14 is connected to a voltage source 340, while an anode side of each of the varactor diodes 13 and 14 is connected to a ground voltage (Gnd) in the VCO shown in Figure 1. A voltage of the voltage source 340 is set to be higher than the voltage of the power input terminal. This configuration can be applied to any of the VCOs according to the first to seventeenth embodiments described with reference to Figures 1 to 17.

Figure 19 is a circuit block diagram showing an exemplary configuration in the case where the VCO shown in Figure 5 is controlled by a PLL.

In Figure 19, reference numeral 1 denotes a reference signal oscillator, 2 denotes a phase comparator, 3 denotes a loop filter, and 4 denotes a divider. The phase comparator 2 compares the phase of a signal from the reference signal oscillator 1 with the phase of a signal obtained by dividing a signal from the output circuit 5 of the VCO with the divider 4, and the loop filter 3 smoothes the result of the phase comparison and outputs an output signal to the voltage input terminal of the VCO. Figure 21 is a circuit diagram showing an exemplary configuration of the phase comparator 2 and the loop filter 3. The phase comparator 2 includes a phase comparator circuit, current sources 37 and 38, a voltage source 63, and switches 77 and 78, and has a charge pump function. With this configuration, an oscillation frequency of the VCO can be controlled to be constant, and in the case of changing the oscillation frequency of the VCO, it can be changed by changing a division ratio of the divider 4.

In the case of a frequency modulation operation, the switches 77 and 78 are opened, so that the output impedance of the phase comparator 2 is placed forcibly in a high impedance state. The voltage of the voltage input terminal of the VCO is fixed by capacitors 75 and 76 configuring the loop filter 3. In this state, a current is input to and output from the modulation current terminal, thereby performing a modulation operation.

The PLL circuit shown in Figure 19 can be configured in the same manner also with respect to the VCOs shown in Figures 1 to 18.

As described above, the VCO with a modulation function of the present invention has a circuit configuration in which a frequency modulation factor is expressed as a function of Kv. Therefore, it is possible to configure easily a compensation circuit that allows a predetermined modulation factor

to be obtained even when there are variations of respective circuit elements.